In-flight Water Quality Monitoring on the International Space Station: Measuring Biocide Concentrations with Colorimetric Solid Phase Extraction

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Access to representative water quality data is critical to ensuring that a safe supply of potable water is available to the crew on the International Space Station (ISS). At the present time, the vast majority of the water quality data from the environmental control and life support systems on the ISS are obtained by analyzing archive water samples that are collected in flight and returned to the ground. There are several limitations inherent in this archival approach to water quality monitoring, most notably the time lapse between sample collection and ground analysis. Samples collected on orbit must be stored until they can be returned to the ground for analysis. Typical on-orbit storage times for water samples can range from 1 to 4 months, but in certain circumstances storage times can be much longer due to launch delays and limited return payload capacity. This time lapse between sampling and analysis precludes implementation of real-time adjustments or corrective actions when water does not meet specifications.

After the final space shuttle mission, there will be a sharp decrease in available return-payload mass. Inevitably, this will limit both the volume and total number of environmental samples that can be returned to the ground for analysis. At that point, it will no longer be feasible to rely on archive water samples for detailed water quality data. New hardware systems capable of monitoring multiple water quality parameters in flight on the ISS will need to be developed to ensure representative water quality data can be collected.

The unique operational environment on the ISS and the rigorous safety regulations applied to hardware deployed on the ISS dictate that any water quality monitoring system developed for use in flight possess several key characteristics. "Ideal" water quality monitoring systems must be small, lightweight, reliable, sensitive, provide direct real-time readout of results, minimize waste, contain no hazardous materials, meet strict storage and power guidelines, and function effectively in zero gravity. The ideal system would also be based on a platform technology that can be readily adapted to monitor multiple analytes with minimal hardware modifications. Finally, any system designed for use in flight must be rapid and easy to use so that the crew time required for training and operation on orbit is minimal. One technology that embodies many of the characteristics of the ideal water quality monitoring platform for the ISS, including the ability to add capability with minimal hardware modifications, is Colorimetric Solid Phase Extraction (CSPE).

CSPE is a sorption-spectrophotometric technique that combines colorimetric reagents, solid-phase extraction, and diffuse reflectance spectroscopy to quantify trace levels of target analytes in water samples. In CSPE, a syringe is used to meter a known volume of sample through an analysis cartridge that contains a membrane disk impregnated with an analyte-specific colorimetric reagent and any additives required to optimize the complexation of the reagent and analyte. As the sample is passed through the analysis cartridge, analytes are selectively extracted and complexed on the membrane. Formation of the analyte-reagent complex causes a detectable change in the color of the membrane disk that is proportional to the analyte concentration. The analyte is then quantified by measuring the color of the membrane disk surface using a handheld diffuse reflectance spectrophotometer. This entire process is illustrated in figure 1.

An experimental water quality monitoring kit—the Colorimetric Water Quality Monitoring Kit (CWQMK)—was designed and flown as a Station Development Test Objective (SDTO) experiment to evaluate the suitability of CSPE technology for routine use on the ISS. The experiment—SDTO #15012-U "Near Real-time Water Quality Monitoring Demonstration for ISS Biocides Using Colorimetric Solid Phase Extraction (CSPE)"—was launched on STS-128/17A and initially deployed on the ISS in September 2009. A photo of the CWQMK hardware and a photo from one of the initial in-flight analysis sessions are provided in figure 2. The primary purpose of

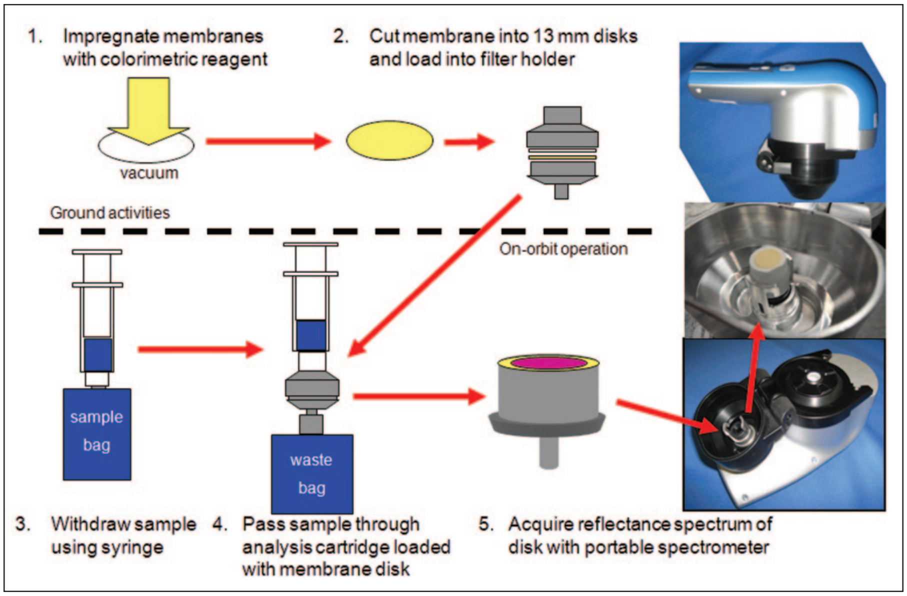

Fig. 1. *Overview of Colorimetric Solid Phase Extraction analysis.*

Fig. 2. *Colorimetric Water Quality Monitoring Kit packaged for launch (left), and International Space Station crew member conducting and in-flight analysis session (right).*

the SDTO experiment was to demonstrate the capability to collect in-flight water quality data on the ISS using CSPE technology. This was accomplished by measuring ionic silver and molecular iodine concentrations in ISS water samples on orbit with the CWQMK. Silver and iodine were selected as test analytes for the SDTO experiment because they are the biocides used in the potable water storage and distribution systems on the ISS.

Biocides are added to the potable water systems on spacecraft to inhibit microbial growth. On the U.S. segment of the ISS molecular iodine serves as the biocide, while the Russian space agency uses silver as a biocide in their systems. These biocides pose a unique challenge for water quality monitoring. For most environmental contaminants, the goal is to ensure the concentration of the contaminant does not exceed a threshold value. With biocide monitoring, the goal is twofold: the biocides must be maintained at a level sufficient to control bacterial growth, but low enough to avoid any negative effects on crew health. As such, ensuring that biocides are maintained at safe, effective levels was a perfect application to illustrate the need for in-flight water quality monitoring systems to ensure the health and safety of spaceflight crews.

In all, 13 in-flight analysis sessions were run with the CWQMK as part of the SDTO experiment. During each in-flight session, ground-supplied standard solutions and water samples collected from different points on the ISS were analyzed with the CWQMK hardware. Samples were collected from both the U.S. and Russian segments of the ISS, and were analyzed in triplicate to assess the reproducibility of the CSPE methods. Ground experiments were conducted in parallel with the in-flight analysis sessions to serve as a control for the in-flight analyses. The ground experiments were used to assess the stability of the standard solutions and analysis cartridges as well as check for any degradation in performance that may have occurred as a result of exposure to launch environments and storage conditions on the ISS.

Data collected with the CWQMK during the SDTO experiment are summarized in Table 1. Results obtained from ground analysis of archive samples collected at the same time as the sample analyzed with the kit are also included in the table. While some differences are apparent, most of these are due to an anomalous result from one of the replicate analyses. When these anomalous points are excluded from calculations, the mean results obtained in flight show excellent agreement with the results obtained using standard laboratory methods. In other instances, information contained in crew notes provides insight into difficulties encountered during the analysis sessions that could be responsible for the observed differences.

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continued

Table 1. *Results from Station Development Test Objective Experiment*

	Concentrations Measured by Session Number (mg/L)												
Solution	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Silver standard	0.404	0.315	0.277	0.236	0.236	0.268	0.537	0.290	0.253	0.205	0.237	0.211	0.136
Sample from SVO-ZV[1]	<0.100	<0.100	<0.100	<0.100	0.397	0.100	0.225	<0.100	<0.100	<0.100	<0.100	<0.100	0.163
	-	<0.100	<0.100	<0.100	0.108	-	0.245	-	<0.100	<0.100	<0.100	<0.100	<0.100
	-	-	<0.100	<0.100	<0.100	-	0.250	-	<0.100	<0.100	<0.100	<0.100	<0.100
Archive from SVO-ZV	0.023	0.081	0.018	0.056	0.069	0.090	0.086	0.125	0.044	0.050	0.060	N/A	0.035
Iodine standard	2.79	1.95	1.33	1.49	0.32	1.04	1.32	0.90	1.00	0.94	0.36	N/A	N/A
Sample from PWD[2] dispensing needle	<0.20	<0.20	<0.20	-	-	-	<0.20	<0.20	-	<0.20	-	<0.20	<0.20
	-	<0.20	<0.20	-	-	-	1.44	-	-	<0.20	-	<0.20	<0.20
	-	<0.20	-	-	-	-	1.40	-	-	-	-	<0.20	<0.20
Archive from PWD dispensing needle	<0.050	<0.050	<0.050	-	-	-	<0.050	<0.050	-	<0.050	-	<0.050	<0.050
Sample from PWD aux. port	-	-	-	1.04	0.74	0.38	-	-	1.45	-	1.63	-	-
	-	-	-	0.63	0.33	-	-	-	0.74	-	1.69	-	-
	-	-	-	0.63	0.71	-	-	-	0.80	-	1.68	-	-
Archive from PWD aux. port	-	-	-	N/A	1.11	<0.050	-	-	N/A	-	2.05	-	-

N/A = not analyzed
[1] Russian system for dispensing ground supplied water
[2] Potable Water Dispenser

Based on the success of the SDTO experiment, the CWQMK was certified as operational hardware in April 2011. As part of the certification process, the kit was augmented to provide the capability to measure total iodine compounds (defined as the sum of the concentrations of molecular iodine, iodide, and triiodide). Addition of this capability required no hardware modifications; the only changes to the kit were the incorporation of total iodine reagent cartridges and a minor firmware update for the diffuse reflectance spectrophotometer that can be performed on orbit. With this added capability, the CWQMK provides a means to meet a previously unmet requirement to monitor biocidal iodine and total iodine compounds in water samples collected from the U.S. segment of the ISS.

Development of the CWQMK and the SDTO experiment were collaborative efforts that paired researchers from NASA Johnson Space Center with partners in academia and industry. Method development work is ongoing. The team is evaluating additional applications for CSPE technology in both spacecraft and terrestrial environments. Specific compounds under evaluation include nickel, acetone, acetate, ammonia, and ortho-phthalaldehyde.